BENTON HARBOR POWER PLANT LIMNOLOGICAL STUDIES

PART XVIII. EFFECT OF A THERMAL DISCHARGE ON BENTHOS POPULATIONS: STATISTICAL METHODS FOR ASSESSING THE IMPACT OF THE COOK NUCLEAR PLANT

Edward M. Johnston

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STATISTICAL METHODS FOR ASSESSING THE IMPACT
OF THE COOK NUCLEAR PLANT

Abstract. In conducting a survey of conditions in Lake Michigan near the Cook nuclear plant, we needed statistical methods for assessing disturbance of the benthic community due to operation of the plant. This is a progress report on our statistical program.

Two methods are described which will help assess the magnitude of changes and compare them to the known level of random variations. Both methods make use of an arrangement of the stations into depth zones. Within each zone there is an inner group and an outer group. The inner stations should be affected most by any impact of the thermal discharge. We are interested in the comparison of the mean density of a certain taxon in the inner and outer groups of stations in a given depth zone. When plant operation starts, if the thermal discharge is having any effect then the relative sizes of the inner and outer populations should change.

The first method is a graphical technique for comparing inner and outer populations of a given taxon. With its aid, the biological situation can be followed through successive years. Both spatial and temporal standard errors are represented in the figure. This method permits an intuitive judgment on whether the magnitude of an observed change is greater than the normal year-to-year fluctuations.

The second method uses a 5-way analysis of variance, after applying a logarithmic transformation to the densities of animals per square meter. The statistical test for a heat effect is then the F-test of the interaction of the inner/outer and before/after factors.

It should be possible to apply these methods to phytoplankton and zooplankton as well as benthos.

INTRODUCTION

This report presents two statistical methods that will assist us in making a final judgment on the effect of the plant. We will apply the usual tests of statistical significance wherever appropriate. However, statistical significance is not the same as biological significance. The final judgment will be a biological one.

METHODS AND RESULTS

<u>Data to be examined</u>:

As part of the pre-operational survey at the Cook Plant, benthos data were collected in 1970 and 1971 using a 46-station grid four times a year, in April, July, September and November. The samples have been counted to major taxa in all cases and to species in selected cases. In this report, "major taxa" refers to the following six groups: amphipods, oligochaetes, sphaériids, chironomids, leeches and snails.

The surveys included in this analysis are as follows:

Year	Months			
1970		July	September	November
1971	April	July	September	November
1972	April	July		

<u>Grouping of the stations:</u>

The grid of stations from which most of the data were taken is described in Table 1. A map showing most of these stations is given in Figure 1. The grid was not specifically designed to permit statistical analysis, but it is relatively simple to use it for that purpose. When plant operation starts, if the thermal discharge is having any effect then benthos populations near the

TABLE 1

<u>The DC, NDC and SDC Stations: A Table showing their Transects and Distances from Shore</u>

Entries in the 'Transect' columns are interpreted as follows. Stations in the row marked '0.00' are on the DC transect, which leaves shore right at the plant (41° 58.5' N., 86° 34.0' E.) and runs in a westnorthwesterly direction with bearing 290°. The other transects are parallel to this one; their distances from it are indicated in the 'Transect' columns in both miles and kilometers. Positive distances refer to transects north of the plant; negative distances refer to transects south of the plant. The distance of each station from shore is measured along the transect and is given here in both miles and kilometers. Metric distances have been rounded to the nearest multiple of 0.40 km.

*Stations marked with an asterisk have not been used in major surveys since May 1, 1972.

Transect		Distance of each station from shore (km. and miles)								
		0.00	0.40	0.80	1.20	1.60	2.00	3.60	6.40	11.20 (km.)
km.	mi.	0.00	0.25	0.50	0.75	1.00	1.25	2.25	4.00	7.00 (mi.)
-11.20	-7.00		SDC-7-1	SDC-7-2*			SDC-7-3	SDC-7-4*	SDC-7-5	
-6.40	-4.00	SDC-4-0	SDC-4-1	SDC-4-2*				SDC-4-3		SDC-4-4
-3.20	-2.00	SDC-2-0	SDC-2-1	SDC-2-2*			SDC-2-3		SDC-2-4*	
-1.60	-1.00	SDC-1-0	SDC-1-1		SDC-1-2			SDC-1-3*		
-0.80	-0.50	SDC-.5-0	SDC-.5-1*	SDC-.5-2			SDC-.5-3*			
-0.40	-0.25				SDC-.25-1*					
0.00	0.00		DC-1		DC-2		DC-3	DC-4	DC-5	DC-6
0.40	0.25				NDC-.25-1*					
0.80	0.50	NDC-.5-0	NDC-.5-1*	NDC-.5-2			NDC-.5-3*			
1.60	1.00	NDC-1-0	NDC-1-1		NDC-1-2			NDC-1-3*		
3.20	2.00	NDC-2-0	NDC-2-1	NDC-2-2*			NDC-2-3		NDC-2-4*	
6.40	4.00	NDC-4-0	NDC-4-1	NDC-4-2*				NDC-4-3		NDC-4-4
11.20	7.00		NDC-7-1	NDC-7-2*			NDC-7-3	NDC-7-4*	NDC-7-5	

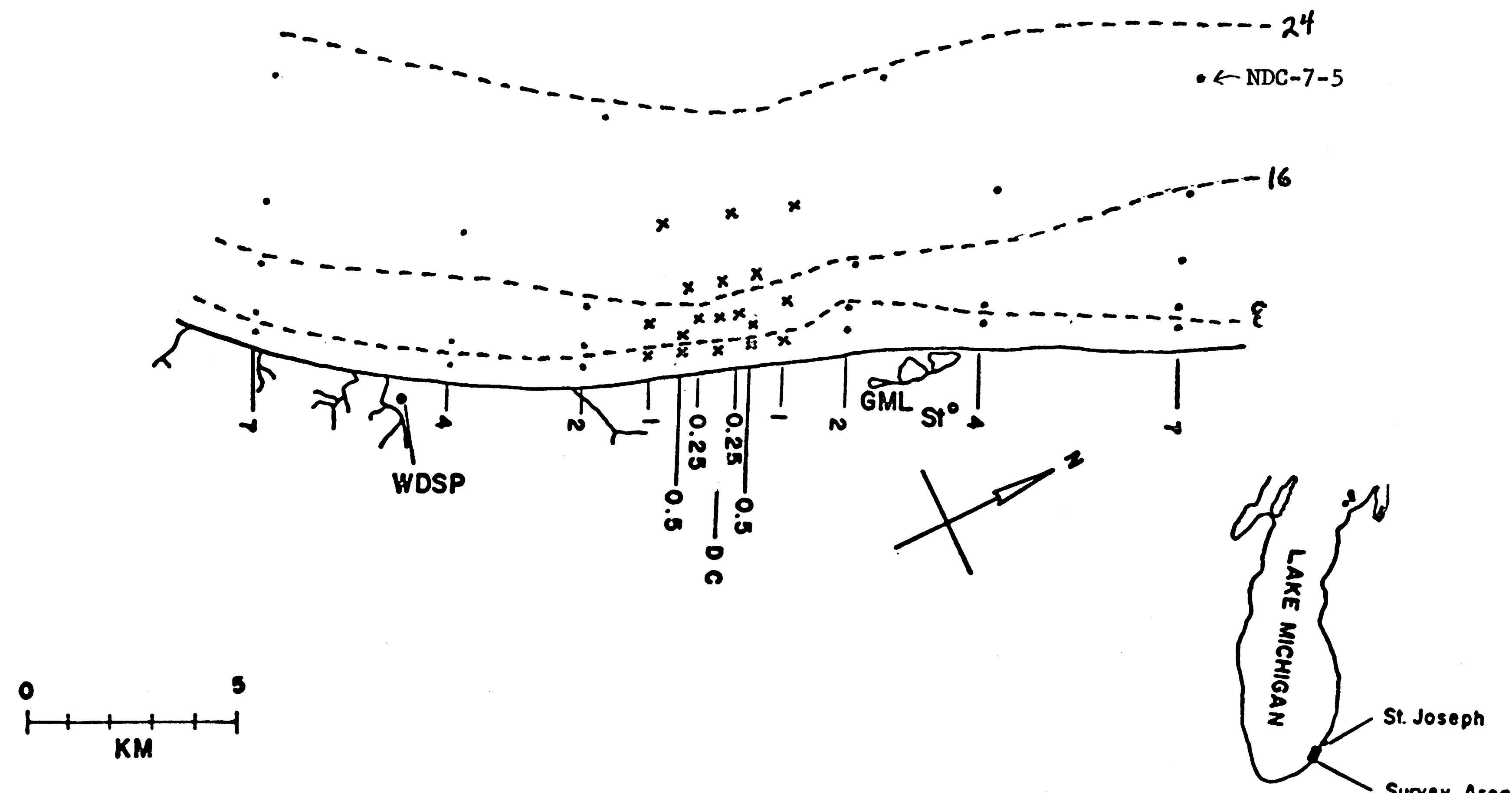

Figure 1. A map showing the stations used in this report. The depth zones are 0-8 meters, 8-16 meters and 16-24 meters. The inner stations within each zone are indicated by crosses and the outer stations by dots.

Stations whose names begin with 'DC' are on the transect that meets shore right at the plant location. NDC transects are to the north of the plant; SDC transects are to the south. The distance of each transect from the plant in miles is indicated on the map. NDC-7-5 is the 5th station from shore on the transect 7 miles north of the plant.

outfall should change from their "normal" values. However, populations vary widely even without any human disturbance. We have decided to use stations far from the plant (outer) as control stations and stations near the plant (inner) as test stations. Changes in ambient lake conditions or seasonal changes should affect both test and control stations equally. Changes due to the plant's discharge should disproportionately affect the test stations and thus alter the ratio of test to control populations.

The arrangement of stations into test and control groups is shown in Table 2. Notice that only stations in the same depth zone are being compared to one another. We have defined the following depth zones: 0-8 meters, 8-16 meters, 16-24 meters, and greater than 24 meters. These are the same zones as were used for analysis in a previous report of benthos data from this project (Mozley 1973). The stations that lie in each depth zone have been divided into two groups--an inner group and an outer group. The 0-8 meter zone is designated as A, the 8-16 meter as B and the 16-24 meter as C. Within each zone the inner stations are referred to by the letter I and the outer stations by O. This produces the six combinations AI, AO, BI, BO, CI and CO. The names of the stations in each group are shown in Table 2. The location of each named station can be found by consulting Table 1.

Of the original 46 stations, 4 were in a water depth greater than 24 meters. These were not included in the analysis because no appropriate grouping of them into inner and outer was possible.

For two of the sampling dates the makeup of the station groups differed from that shown in Table 1. In the July 1970 survey, NDC-.25-1 and SDC-.25-1 were not taken. This resulted in 5 stations in group BI rather than 7 as in the other surveys. In the July 1972 survey the 46-station grid was not used

TABLE 2

Arrangement of Stations into Inner and Outer Groups:
I. Old Grid Stations: July 1970 through April 1972

For each depth zone there is an inner and an outer group of stations. The letters used in the names of the groups have the following meanings: A, 0-8 meters; B, 8-16 meters; C, 16-24 meters. The letter I means 'inner' and O means 'outer'.

These groups apply to the station grid used from July 1970 through April 1972. Major surveys since that time have used a systematic random arrangement of stations for collecting benthos data, to which this table does not apply.

Depth Range	Inner Group	Outer Group	
0-8 meters	AI	AO	
	DC-1	NDC-2-1	
	NDC-.5-1	SDC-2-1	
	SDC-.5-1	NDC-4-1	
	NDC-1-1	NDC-7-1	
	SDC-1-1	SDC-4-1	
		SDC-7-1	
		NDC-2-2	
8-16 meters	BI	BO	
	DC-2	NDC-2-3	SDC-2-2
	NDC-.25-1	NDC-4-2	SDC-2-3
	NDC-.5-2	NDC-7-2	SDC-4-2
	NDC-1-2	NDC-7-3	SDC-7-2
	SDC-.25-1	NDC-7-4	SDC-7-3
	SDC-.5-2		
	SDC-1-2		
16-24 meters	CI	CO	
	DC-3	NDC-2-4	
	DC-4	NDC-4-3	
	NDC-.5-3	NDC-7-5	
	NDC-1-3	SDC-2-4	
	SDC-.5-3	SDC-4-3	
	SDC-1-3	SDC-7-4	
		SDC-7-5	

The meaning of the station symbols is explained in Table 1.

at all, and the station positions were chosen by a systematic random sampling method. Details of the method are given on p. 214 ff. of Mozley (1973). The depth zones used in laying out the stations had boundaries at 8, 16 and 24 meters, so it was quite straightforward to arrange the new stations into groups that paralleled those used with the old grid. The new groups are shown in Table 3, and the positions of the stations can be seen in Figure 2.

Graphical comparison of inner and outer densities of benthic animals:

Most of the data to be analyzed are given in Table 10 of Ayers et al. (1971) or in Tables 38-44 of Mozley (1973). The data for July 1972 have not appeared as a table but are shown graphically in Figure 47 of the latter work.

The means of the inner and outer groups of stations for the quantity Total Animals per Square Meter are shown in Figures 3-6 of this report. Figure 3 indicates the general appearance of the data. It gives the results from the B depth zone (8-16 meters) for the two April surveys. The 7 inner stations in the B zone constitute the group BI. The average abundance at those stations is plotted along the horizontal axis. The 10 outer stations in the B zone constitute the group BO. The average abundance at those stations is plotted along the vertical axis. The horizontal error bars shows the standard error of the mean of the 7 inner observations; the vertical error bars show the standard error of the 10 outer observations. A similar graphical method for examining benthos data was presented by Beak Consultants (1973).

In the interests of brevity we only consider Total Animals in this report. Similar graphs could be prepared for each major taxon and each sampling month. Such a presentation would be more meaningful after all the pre-operational and some of the post-operational data were available.

TABLE 3

Arrangement of Stations into Inner and Outer Groups:
II. Systematic Random Survey Stations: July, 1972

These are the names of the stations in the inner and outer groups within each depth zone in the systematic random survey of July 1972. The number of replicate grabs taken at each station is given in parentheses following the station name. Positions of the stations are shown in Figure 2. Stations with depth greater than 24 meters were not included in the analysis.

Depth Range	Inner Group	Outer Group
0-8 meters	AI	AO
	D01 (5)	N01 (5)
	D02 (5)	N02 (5)
	D03 (5)	N03 (5)
		S01 (5)
		S02 (5)
		S03 (5)
8-16 meters	BI	BO
	D11 (3)	N11 (3)
	D12 (3)	N12 (3)
	D13 (3)	N13 (3)
		S11 (3)
		S12 (3)
		S13 (3)
16-24 meters	CI	CO
	D21 (3)	N21 (3)
	D22 (3)	N22 (3)
	D23 (3)	N23 (3)
		S21 (3)
		S22 (3)
		S23 (3)

The meaning of the station symbols is explained in Mozley (1973).

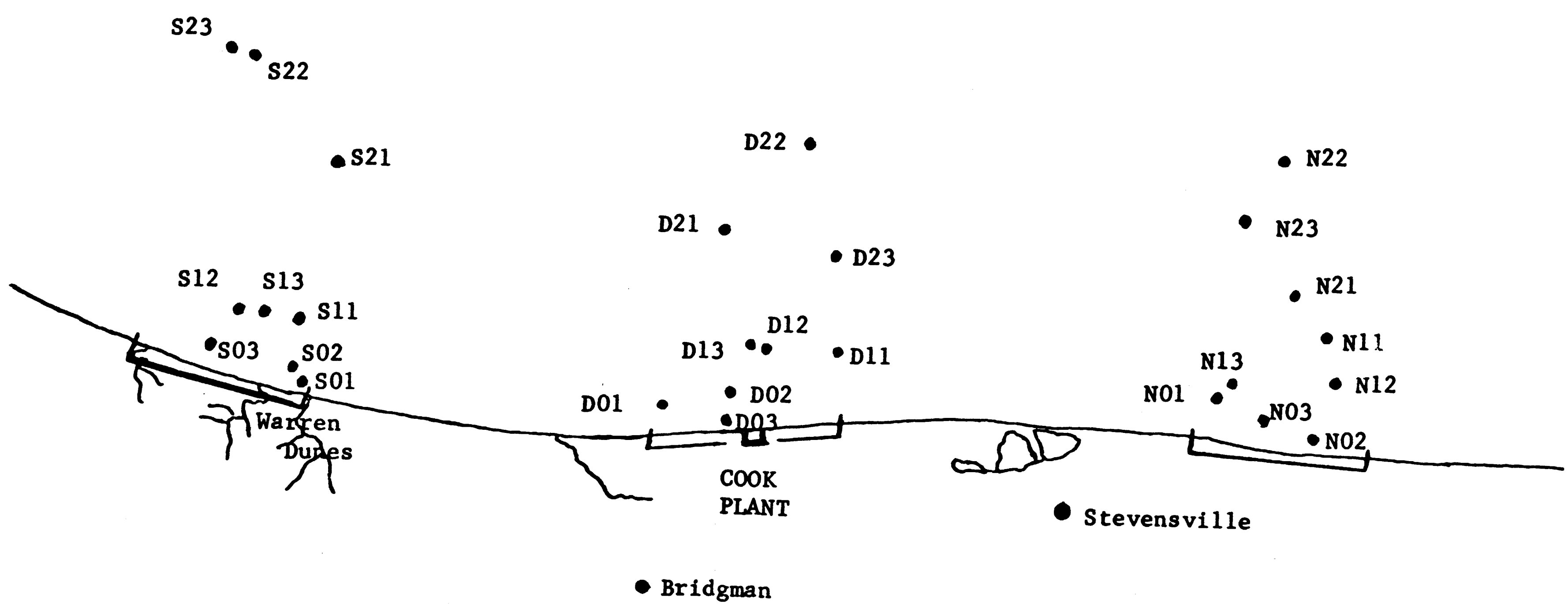

Figure 2. A map showing the station positions in the systematic random survey of July, 1972. For the method used to determine positions, see Mozley (1973), pp. 214 ff. The letter in each station name refers to the region -- N, D or S. The first digit indicates the depth zone; the second digit is the station number within that zone.

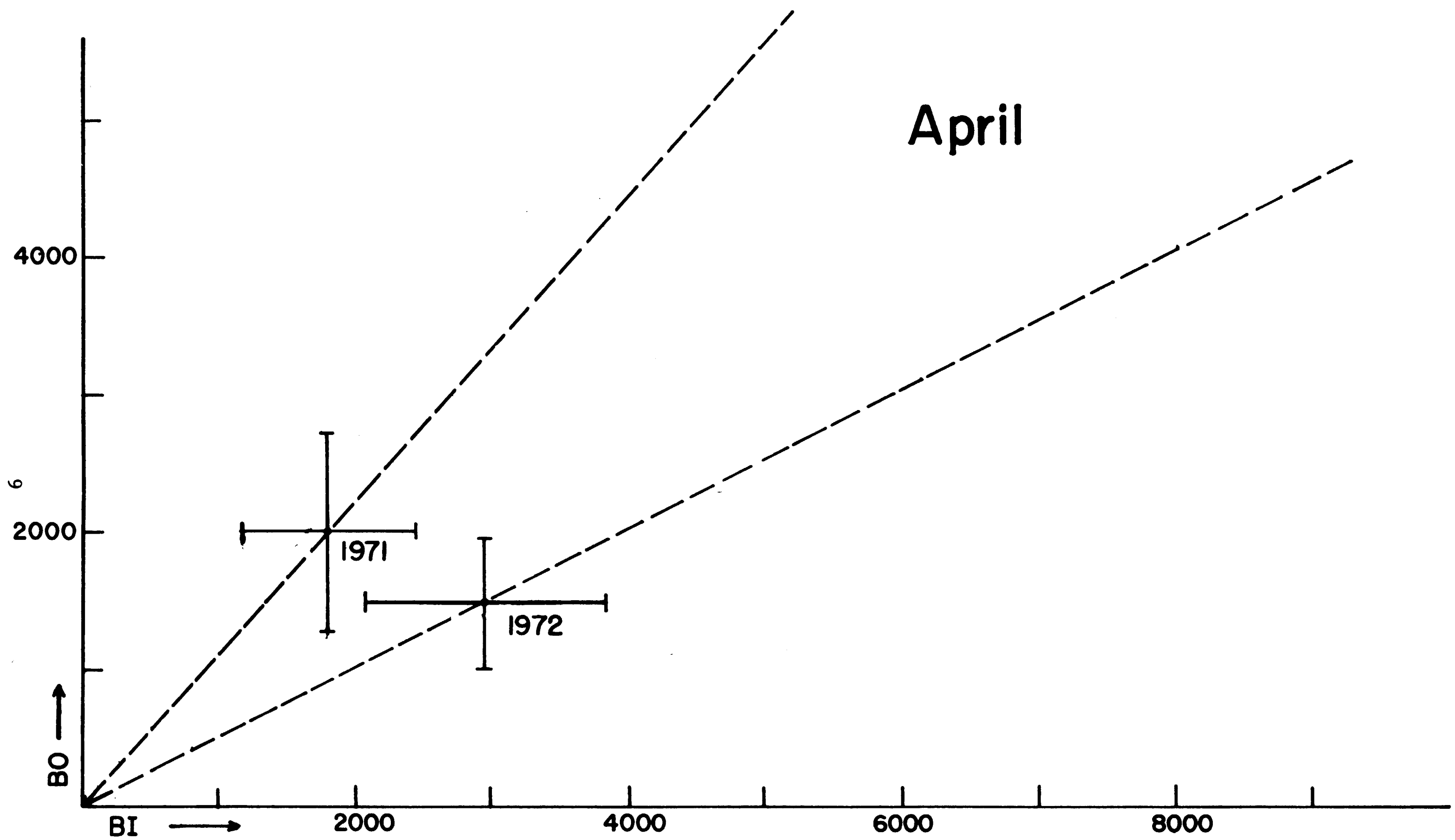

Figure 3. <u>April 1971 and April 1972, Zone B, Total Animals per Meter^2</u> (depth 8-16 meters)

The 7 inner stations in the B zone constitute the group BI. The average abundance at those stations is plotted along the horizontal axis. The 10 outer stations in the B zone constitute the group BO. The average abundance at those stations is plotted along the vertical axis. The horizontal error bars show the standard error of the mean of the 7 inner observations; the vertical error bars show the standard error of the 10 outer observations. The two dashed lines correspond to the mean plus or minus the standard error of the I/O measurements. The April 1971 value and the April 1972 value are the two measurements in this case.

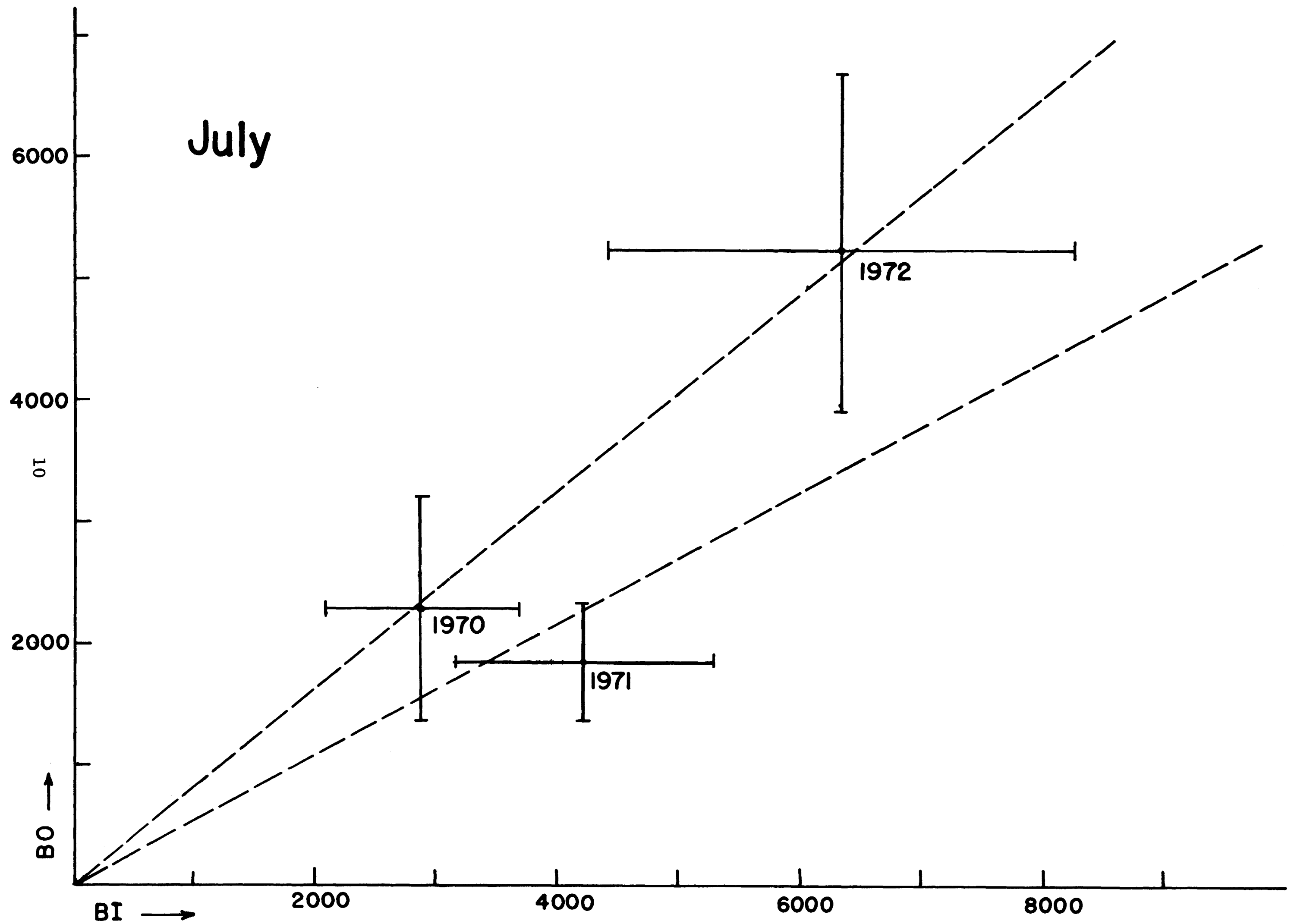

Figure 4. July 1970, July 1971, July 1972; Zone B (8-16 meters), Total Animals per Meter^2

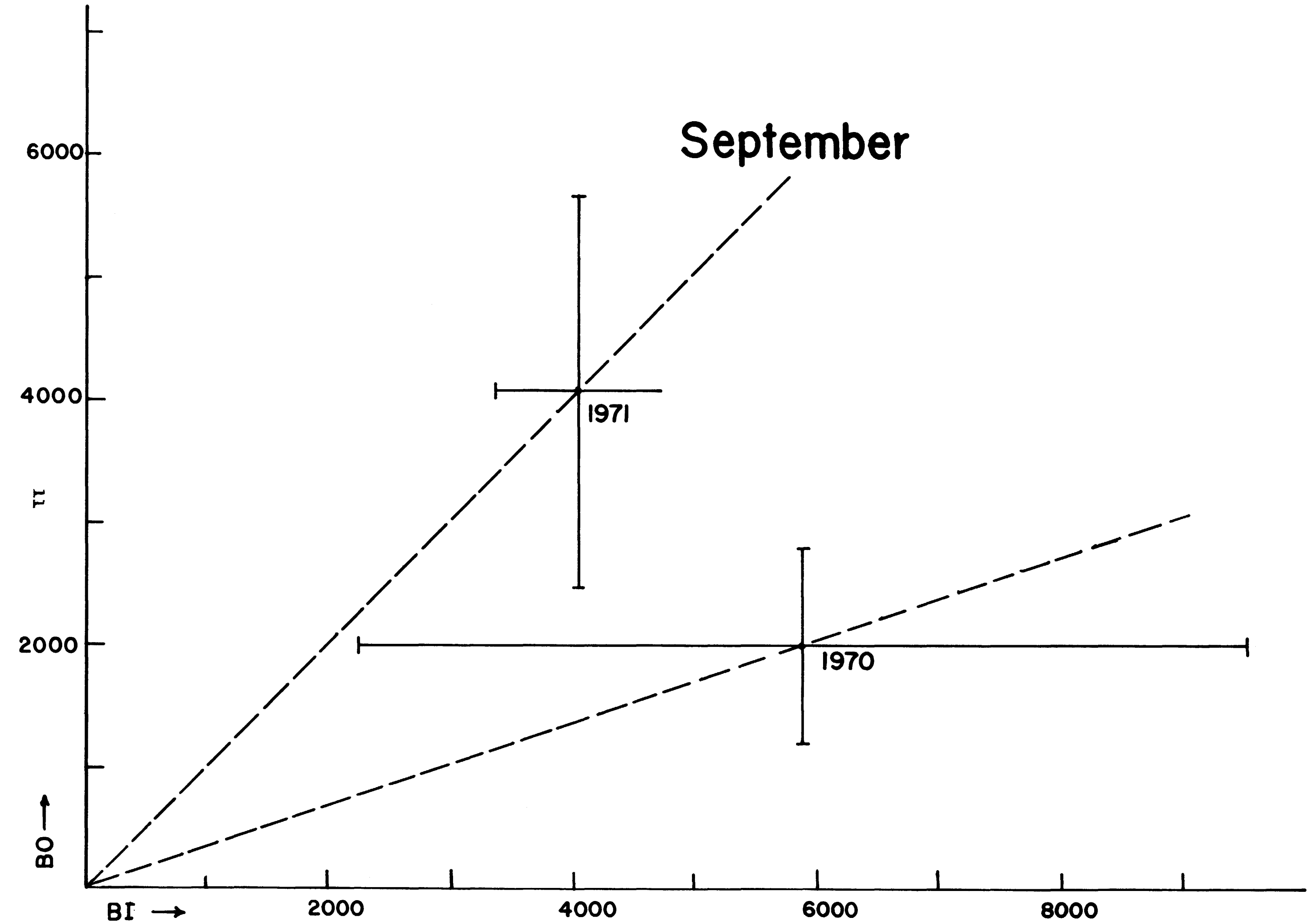

Figure 5. September 1970 and September 1971, Zone B (8-16 meters), Total Animals per Meter^2

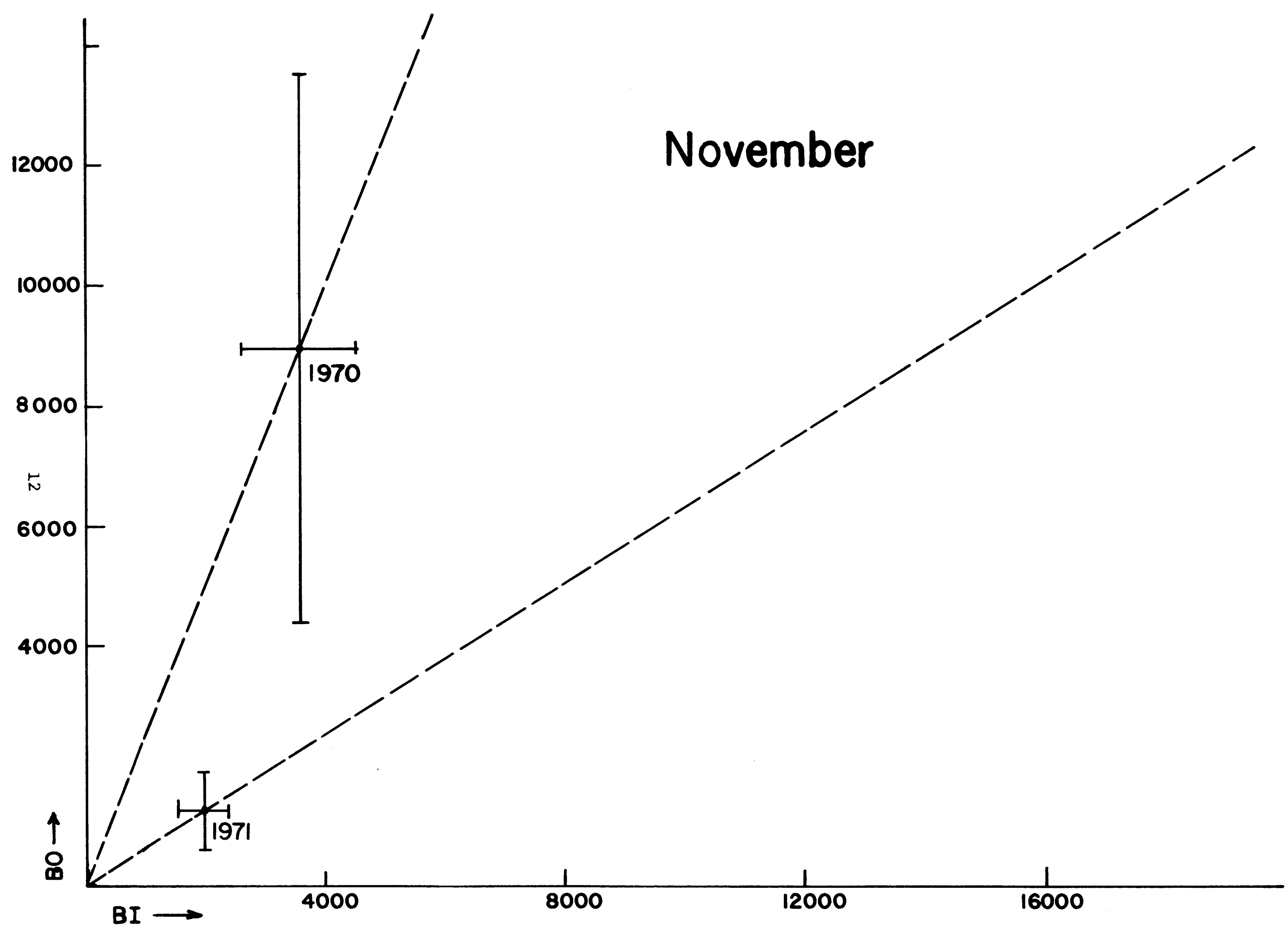

Figure 6. November 1970 and November 1971, Zone B (8-16 meters), Total Animals per Meter^2
Note that the scale is different from the one used in Figures 3-5

Use of the graphical method to detect a change due to plant operation:

By inspecting the graph, it is possible to tell whether a survey result appears to deviate significantly from the pattern of previous results. The quantity of interest is I/O, the ratio of the average density at the inner stations to the average density at the outer stations for a given survey. Points for which I/O = 1 would lie on a line through the origin making an angle of 45° with the horizontal. If the plant's discharge has an effect on the benthos, we would expect either an increase or a decrease in the population densities at the inner stations compared to their undisturbed values. If the average at the outer stations is used as the undisturbed or control value, then a thermal effect should produce a value of I/O that is significantly different from 1. If heat favors the taxon being studied, then I/O would be greater than 1. If heat inhibits the animal, we would expect I/O to be less than 1.

By paying attention to the ratio I/O rather than to I and O individually, we should avoid being misled by simultaneous changes in I and O, which might result from shifts in ambient lake conditions.

It is useful to plot on the graph some measure of the temporal variability of the data points. We do so as follows. The first step is to compute the ratio I/O for each of the points. Next, we take the logarithm of each ratio and compute the mean and standard deviation of these logarithms. The two quantities: mean plus standard error, and mean minus standard error, are computed. Then we take the antilogarithm of each and plot on the graph the dashed lines that correspond to the two resulting I/O values. (A line joining all points with a given value of I/O will be a straight line through the origin). One advantage of using the log transformation in computing these lines is that negative values of I/O are avoided. The dashed lines indicate the temporal

variability, just as the two error bars at each data point indicate the spatial variability.

Increasing the number of grabs taken in a given zone on a given date should decrease these spatial standard errors because of the factor $1/\sqrt{N}$ in the formula for the standard error. However, there is no way of reducing the temporal standard error except by continuing the survey over a greater number of years. Usually there is a limit to the length of at least the pre-operational part of a survey. This means that the strategem of increasing the value of N (the sample size) in order to decrease the standard error is not available to us in the case of the temporal error. The dashed lines in Figure 3 indicate that the temporal error is already of the same order as the spatial error.

These facts show that a point of diminishing returns is reached when the number of grabs taken in any given survey is increased. If we had taken four times as many grabs in each of the two April surveys we might have reduced the error bars in Figure 3 by a factor of two. But the temporal standard error would, on the average, stay the same. Since the temporal error places a strict limit on our ability to detect a change due to plant operation, little would be gained by such an increase.

To look for seasonal trends in the B zone benthos populations, we have replotted the data of Figures 3-6 with a time axis and show it as Figure 8. The error bars are the standard error of the mean, just as in Figures 3-6. The same information for the other two depth zones, A and C, has been plotted in Figures 7 and 9.

<u>The analysis of variance method</u>:

The graphical method just described permits an intuitive judgment on whether the magnitude of an observed change in the benthos, after plant operation starts, is greater than the normal year-to-year fluctuations. In addition

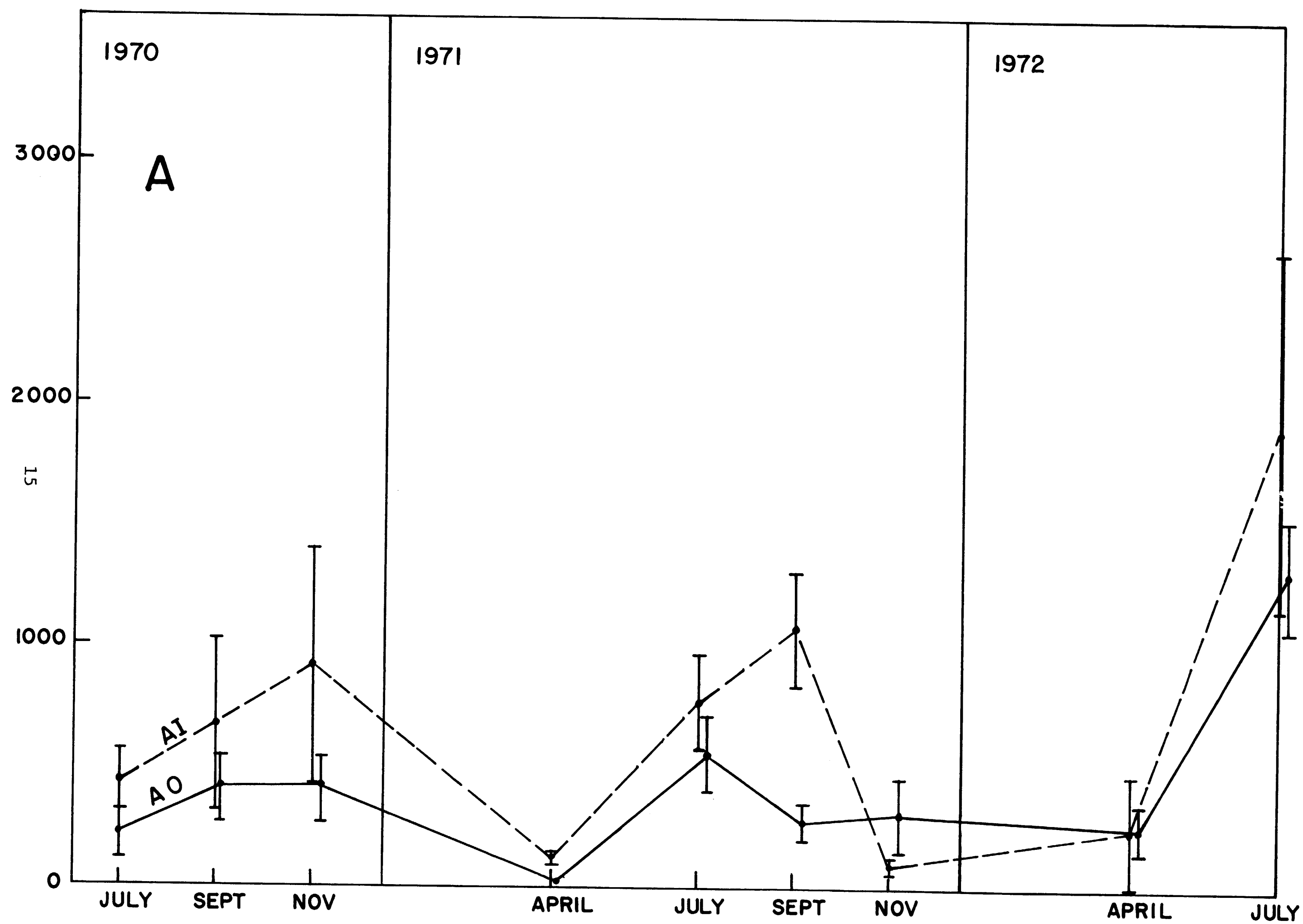

Figure 7. Zone A (0-8 meters): Inner and Outer Abundances as a Function of Time, Total Animals per Meter^2

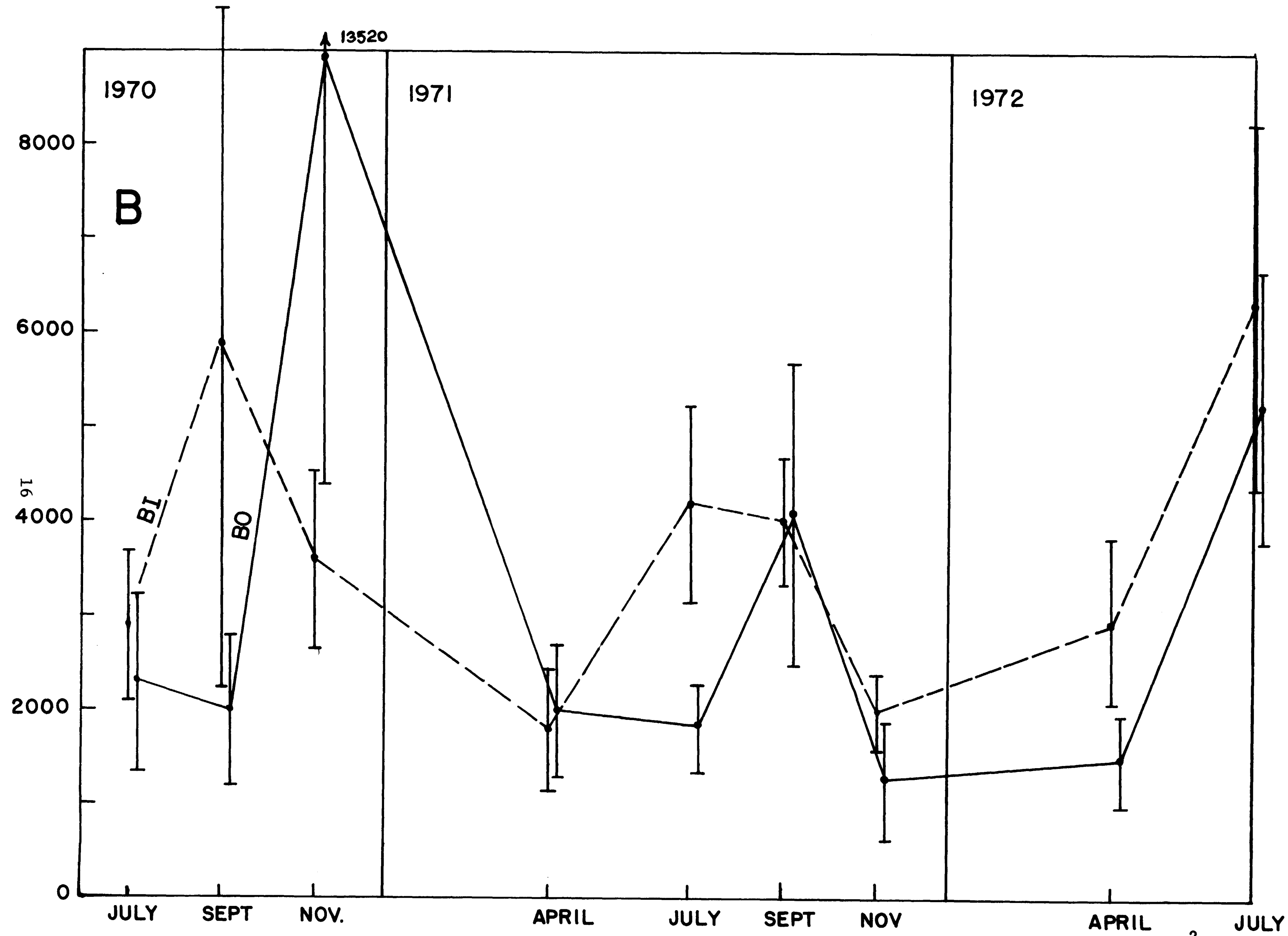

Figure 8. Zone B (8-16 meters): Inner and Outer Abundances as a Function of Time, Total Animals per Meter^2

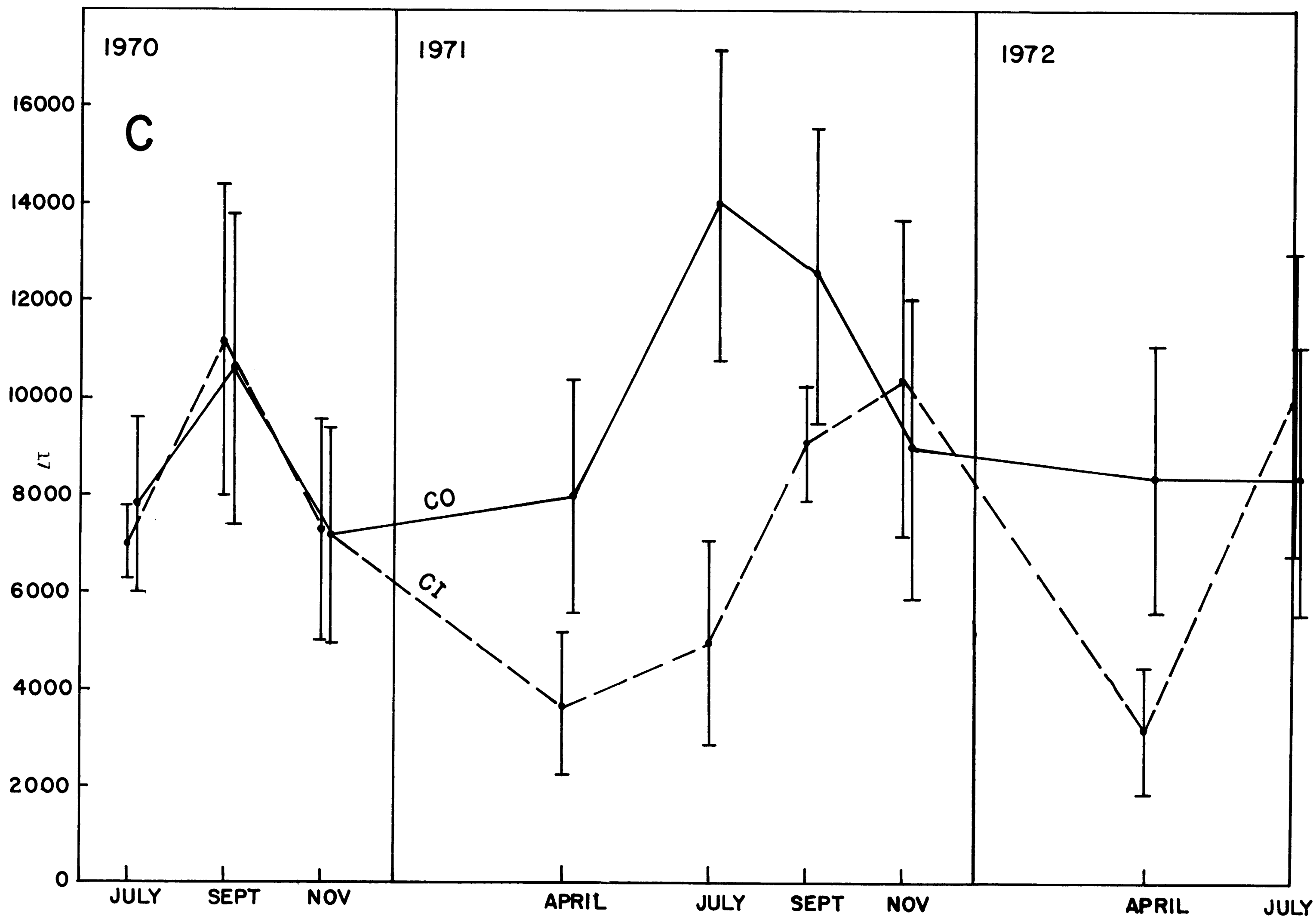

Figure 9. Zone C (16-24 meters): Inner and Outer Abundances as a Function of Time, Total Animals per Meter^2

to the graphical method it is desirable to have a formal method of testing any observed change for statistical significance. The method we have chosen is a five-way analysis of variance. The five factors, the number of levels of each, and the identity of the levels are shown below.

1. Depth zones (3): A, B, C
2. Outfall Distance (2): inner, outer
3. Seasons (3): April, July, and Oct. or Nov.
4. Construction Time (2): before, after
5. Years (8): 1971, 1972, 1973, 1974 (before)
   1975, 1976, 1977, 1978 (after)

This will be a nested analysis of variance (Sokal and Rohlf 1969, p. 253). Years will be nested within Construction Time. The above arrangement of years into "before" and "after" groups assumes a startup date of January 1, 1975. The total number of cells in the ANOVA table can be found by multiplying together the numbers of levels of the factors: 3 x 2 x 3 x 2 x 8 = 288 cells. The cells will contain varying numbers of replicates. Table 2 shows that the number of grabs in each given combination of zone and outfall-distance varies from 5 to 10 in the original grid. Table 3 indicates that the number of grabs goes from 9 to 30 in the systematic random survey plan which has been used since July, 1972. The analysis described could be performed for total animals (all taxa combined) and for each of the following major taxa: amphipods, oligochaetes, sphaeriids and chironomids. The statistical test for a heat effect on a given taxon will be the F-test of the interaction of the Outfall Distance (inner vs. outer) and Construction Time (before vs. after).

One of the assumptions made in the analysis of variance procedure is that the variances are homogeneous (Sokal and Rohlf 1969, p. 369). We will attempt to ensure this by performing a logarithmic transformation on the data from each grab before intering it in the ANOVA table. The transformation used

will be $y = \log (x + 1)$, where x is the number of animals per square meter of the given taxon.

The computer program to be used for this analysis is BMDX64, one of the UCLA Biomedical program series. If the complete analysis described above turns out to be too unwieldy, we will consider various simplifications. By 1976 a year of post-operational data should be available. At that time various methods can be tried out, including the one just described, to see which is the most useful.

A method similar to this one has been described by Garton and Harkins (1970) for the analysis of stream benthos near a power-plant discharge. They proposed a four-way analysis of variance. However, their report used only simulated data. In the absence of real benthos data, it is not possible to judge from their work whether that particular ANOVA method will be the most effective one.

Extension of these methods to phytoplankton and zooplankton:

Both the graphical method and the analysis of variance method appear to be usable with plankton data as well as with benthos. The sessility of benthos implies that the distinction of inner and outer has more meaning for them then for plankton. However, if there are gross changes in the plankton after plant operation starts this should show up both in the inner-outer graphs and in the analysis of variance.

REFERENCES

Ayers, J. C., W. L. Yocum, H. K. Soo, T. W. Bottrell, S. C. Mozley and L. C. Garcia (1971): Benton Harbor Power Plant Limnological Studies, part 9, "The biological survey of 10 July 1970". Great Lakes Research Division, University of Michigan, Ann Arbor, Michigan.

Beak Consultants, Inc. (1973): "Evaluation of pre-operational biological conditions of Lake Michigan in the vicinity of the Palisades nuclear plant." A report to Consumers Power Co., Jackson, Michigan; March 2, 1973.

Garton, R. R. and R. D. Harkins (1970): Guidelines: Biological Surveys at Proposed Heat Discharge Sites. U. S. Environmental Protection Agency, Water Quality Office, 99 pp.

Mozley, S. C. (1973): "Study of benthic organisms", in J. C. Ayers and E. Seibel (ed.), Benton Harbor Power Plant Limnological Studies, part 13, "Cook plant pre-operational studies 1972", pp. 178-242. Great Lakes Research Division, University of Michigan, Ann Arbor, Michigan.

Sokal, R. R. and F. J. Rohlf (1969): Biometry. W. H. Freeman, San Francisco. 776 pp.